

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



September 23, 2016

MATERIALS LABORATORY FACTUAL REPORT

Report No. 16-081

A. ACCIDENT

Place : Chatham, Massachusetts
Date : June 17, 2016
Vehicle : Robinson R44, N141TM
NTSB No. : ERA16LA216
Investigator : Robert Gretz, AS-ERA

B. COMPONENTS EXAMINED

Shaft and bearing assembly

C. DETAILS OF THE EXAMINATION

On June 17, 2016, about 1245 eastern daylight time, a Robinson R44 was substantially damaged during a forced landing into a pond, following a total loss of engine power. The commercial pilot and passenger were seriously injured. Two witnesses reported hearing a sputtering or lack of engine noise, followed by a landing that looked like "a controlled crash." A Federal Aviation Administration inspector examining the wreckage stated that the helicopter, resting on its left side at the edge of the pond, exhibited substantial airframe damage with a rocker arm protruding from the engine crankcase. The engine was a Lycoming O-540-F1.¹ The shaft and bearing assembly were sent to the NTSB Materials Laboratory for further examination.

Figure 1 shows the shaft bearing assembly, as received. Three of the nuts from the through bolts on the forward side had been sheared off, consistent with damage incurred during ground impact. All four bolt heads, which were tapered, were still present in the countersunk holes on the aft side.

The markings on the lower flange are illustrated in Figure 2. The markings indicated the part number was "C181-3" from "Rev G" with a serial number "1722". The part was stated to be from Lot 80. The interior of the bearing inner race, which had been in contact with the shaft, is shown in Figure 3. This surface showed circumferential wear and gouging, consistent with rotational contact with the adjacent shaft under little or no lubrication.

¹ Lycoming O-540 is a family of air-cooled six-cylinder, horizontally opposed fixed-wing aircraft and helicopter engines.

The bearing assembly was disassembled by first removing the through bolts and cross bolts. After removing the attached forward and aft housing flanges, the bearing components would still not rotate or move (see Figure 4a). The housing was sectioned at 90° to separate it from the bearing. During removal, the outer retainer fell away. However, none of the other bearing components could be actuated due to the extensive corrosion. The bearing was a compound double roller bearing (see Figure 4b). Figure 5 shows all of the bearing components disassembled, set out from forward to aft sides. The components consisted of the two inner races, attached to bearing cages with rollers, two outer races, and three spaces: one each forward and aft, and another between the two roller bearings. Each bearing contained 20 cylindrical rollers.

The aft bearing was examined first. After removal of the outer race, the rollers and cage were able to rotate freely about the inner race. Examination of the inner surface of the outer race revealed roller-shaped oxidation deposits, as illustrated in Figure 6. Once the oxidation was removed, there were no other witness marks observed on the outer race consistent with other damage. With the exception of oxidation, no other issues were noted on the components of the aft bearing.

Examination of the forward bearing revealed more damage to the components compared to their counterparts on the aft bearing. Figure 7 illustrates the inner surface of the outer race after cleaning, revealing regularly spaced linear depressions. These witness marks were consistent with true brinelling on the surface from the adjacent rollers. The depressions were present under the surface oxidation, consistent with their positions before being exposed to water (Figure 8). The outer race exhibited an outer diameter of 0.314 inch, a minimum inner diameter of 2.738 inches (due to the flange), and a broader inner diameter of 2.869 inches.

The roller, cage, and inner race assembly are shown in Figure 9. Like the aft bearing, this assembly exhibited heavy oxidation on all the surface components. Unlike the aft bearing, the rollers on the forward bearing could not be moved. It was only after physical sectioning of the cage and inner race that these components were examined.

The cage exhibited a golden-colored appearance and relatively little oxidation, consistent with a copper-based alloy. Figure 10 shows typical sides inside the bearing cage pockets. The pockets exhibited wear marks consistent with contact from the rollers, but showed no indications of gouging, or depressions consistent with excessive wear or sliding. The outer diameter of the cage was measured as 2.64 inches, and the pocket width varied between 0.318 inch and 0.322 inch.

However, examination of the inner surface of the cage found circumferential wear marks consistent with sliding against the inner race (see Figure 11). Dark char deposits were also present on this surface, consistent with exposure of the lubricant or adjacent components to relatively high temperature.

Examination of the rollers found that most of them exhibited witness marks consistent with their final resting location in the pockets of the bearing cage (see Figure

12). There were some indications of ring-shaped wear on the outside of the roller (or “bullseyeing”) on the axial surfaces of the rollers, but it was not excessive enough that discernible depressions were observed. On the inner cylindrical surface, some circumferential sliding marks were observed, consistent with contact on the inner race outer surface. The minimum inner diameter of this part was 1.665 inches, and the maximum outer diameter was 2.420 inches.

The outer face of the inner surface is shown in Figure 13 and Figure 14. The roller groove on the outer surface exhibited oxidation enough to cover much of the underlying detail. Upon removal of the oxide, discernible depressions consistent with deformation from the adjacent rollers was observed. On the crests of these depressions, sliding wear marks were observed (see Figure 15). These marks were consistent with sliding against the adjacent rollers.

In addition, the flanges on the forward and aft sides of the roller groove on the outer surface exhibited deformation. The direction of the flange deformation was consistent with being bent inward towards the rollers. The inner surface of the inner race exhibited severe circumferential wear, including loss of material and gouging marks (Figure 16). These marks were consistent with rotational sliding along the shaft with little to no lubrication, at elevated temperatures.

Specimens from the forward roller bearing components were sectioned, mounted, and polished. The roller, outer race, and inner race cross sections were etched with a 2% Nital solution. The bearing cage was left as polished. All the specimens were inspected using x-ray fluorescence (XRF). The roller, outer race, and inner race of the forward bearing exhibited compositions consistent with AISI 52100 bearing steel (UNS G52986). The cage exhibited a composition consistent with UNS C21000, a gilding brass copper alloy.

Figure 17 shows a portion of a corner of the inner race outer surface. The corner had been machine rounded. Of note in this area was a crack that propagated into the inner race from groove corner. In addition, a dark-colored corrosion pit was found near the corner. In general, much of the inner race contact surfaces exhibited sub-surface corrosion products (as exemplified by the darker portion in Figure 18).

Also of note was a change in the general microstructure in the inner race from the outer and inner surfaces (compare Figure 17 and Figure 18). Figure 19 shows a closer view of the general microstructure of the inner race. This microstructure was typical for a tempered AISI 52100 bearing steel, exhibiting a matrix of martensite, containing primary carbides and some retained austenite. This microstructure was comparable to one of the same material having been austenitized at close to the solid phase transformation temperature and then oil quenching and then tempering.²

² Austenitizing is an annealing heat treatment used in steels to form the elevated temperature austenite phase by heating the alloy above the transformation temperature (approximately 727 °C or 1340 °F). The amount of phase transformation increases with increasing time and temperature.

In contrast, the microstructure of inner surface of the inner race contained coarse plates of tempered martensite (dark) and retained austenite (white), with no indications of carbides (see Figure 20). This microstructure was consistent with one from the same material having heated to higher temperatures (and/or for longer times) than that seen in Figure 19.³

The microstructure of the outer race and rollers were consistent with the microstructure of the outer portion of the inner race: a matrix of tempered martensite, containing primary carbides with some retained austenite (see Figure 21 and Figure 22, respectively). The bearing cage, being a brass, exhibited a two-phase microstructure typical of most α -brass alloys (see Figure 23). No surface discrepancies or material defects were observed in the microstructures of the cage, outer race, or roller specimens.

The hardness of all the components were inspected per ASTM E384 and converted per ASTM E140.^{4,5} The hardness of the inner race measured 56 HRC (616 HK₅₀₀) in areas exhibiting the equiaxed microstructure. The hardness averaged 55 HRC (586 HK₅₀₀) in the areas that exhibited the needle-like microstructure. The outer race had a hardness of 56 HRC (626 HK₅₀₀), and the roller exhibited an average hardness of 47 HRC (466 HK₅₀₀). The cage exhibited a hardness of 68 HRB (122 HK₅₀₀).

Figure 24 illustrates the two fractured halves of the shaft that sits inside the bearing assembly, as received. The shaft exhibited circumferential wear, as well as white and dark ashing, consistent with exposure to elevated temperature. The material adjacent the fracture on both mating faces exhibited material thinning and deformation (see Figure 25).

A closer view of the aft shaft fragment shows the location of the circumferential wear (Figure 26). Most of the shaft damage, concentrated towards the location of the fracture, was located where the forward bearing had been positioned. The forward bearing had exhibited the most damage.

Figure 27 shows a montage optical metallograph of a cross section of the aft shaft through the fracture. Towards the fracture location, the material exhibited signs of deformation, necking, and inward bending. The outer surface exhibited missing material and “bumpiness,” consistent with gouging and material spallation. Figure 28 shows the microstructure of the aft shaft fragment adjacent the fracture surface. The microstructure exhibited plastic deformation at the surface and the presence of white-etching localized

³ H. Burrier, “Bearing Steels,” *ASM Handbook, Vol 1 – Properties and Selection: Irons, Steels, and High-Performance Alloys*. ASM International (1990) pp. 380–388

⁴ ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA

⁵ ASTM E140 – *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*. ASTM International, West Conshohocken, PA

shear bands below the surface. This pattern was consistent with severe plastic deformation and frictional heating from impact abrasion.⁶

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⁶ J.A. Hawk, R.D. Wilson, D.R. Danks and M.T. Kiser, "Abrasive Wear Failures," *ASM Handbook, Vol 11 – Failure Analysis and Prevention*. ASM International. (2002) pp. 906–921

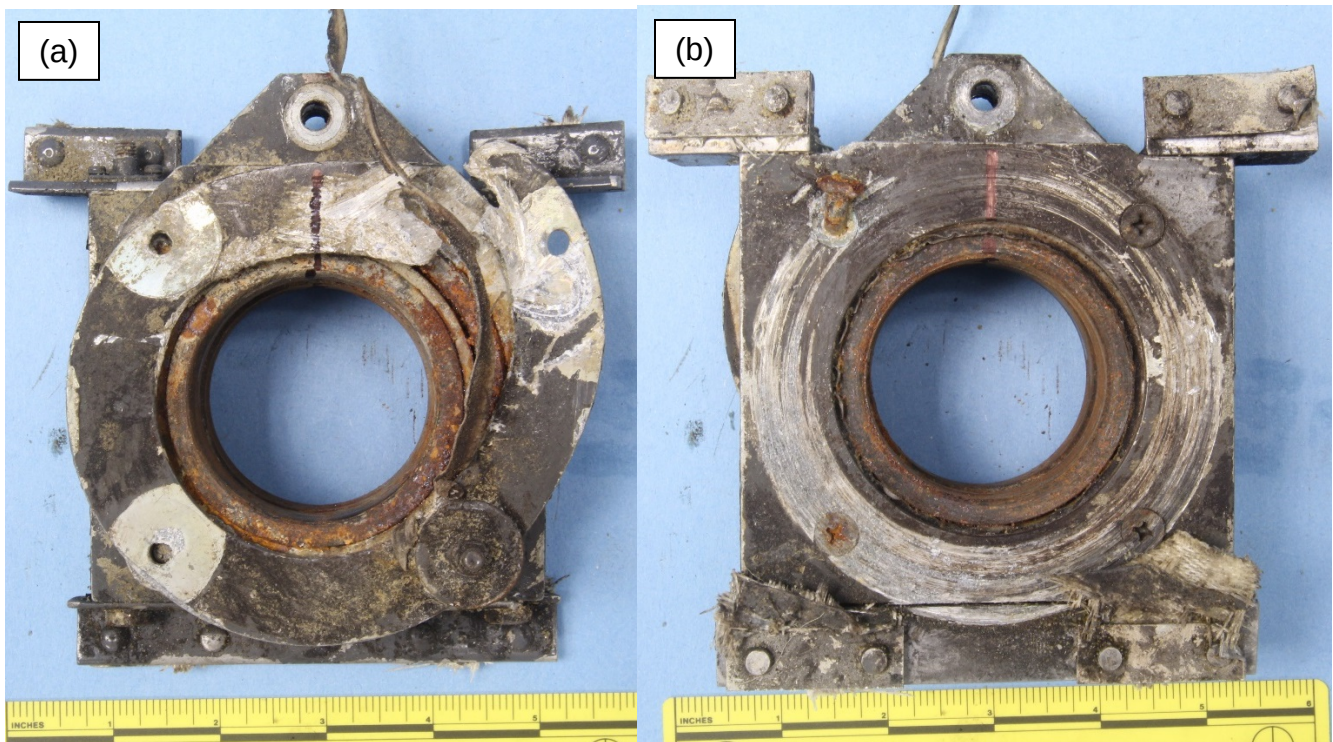


Figure 1 – The R44 shaft bearing assembly, as received, viewed from (a) the forward side and (b) the aft side.



Figure 2 – The markings on the flange of the bearing assembly, as received.



Figure 3 – The interior of the inner race of the aft side of the bearing. The 12 o'clock position was marked on the left side.

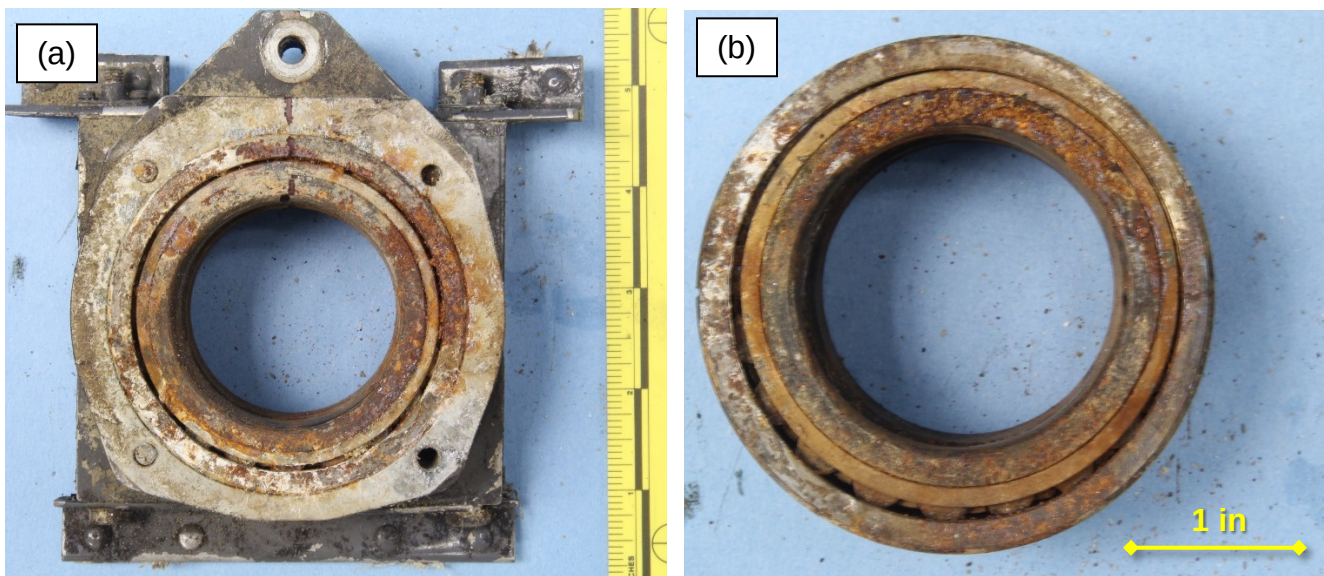


Figure 4 – The bearing assembly, as viewed from the forward side, during disassembly: (a) shows the bearing assembly after removal of the forward housing, and (b) shows the double bearing after removal of the surrounding housing.



Figure 5 – The bearing components, after complete disassembly, ordered from forward side to aft side from left to right.



Figure 6 – Inner surface of the aft bearing outer race, as received. The depressions were consistent with the positions of the rollers while oxidation occurred.



Figure 7 – The inner surface of the forward bearing outer race, after cleaning with acetone. The linear depressions were consistent with true brinelling of the race surface.



Figure 8 – A closer view of the brinelling depressions on the inner surface of the forward bearing race.



Figure 9 – A view of the forward bearing rollers, cage and inner race, viewed from outside, after cleaning with acetone.

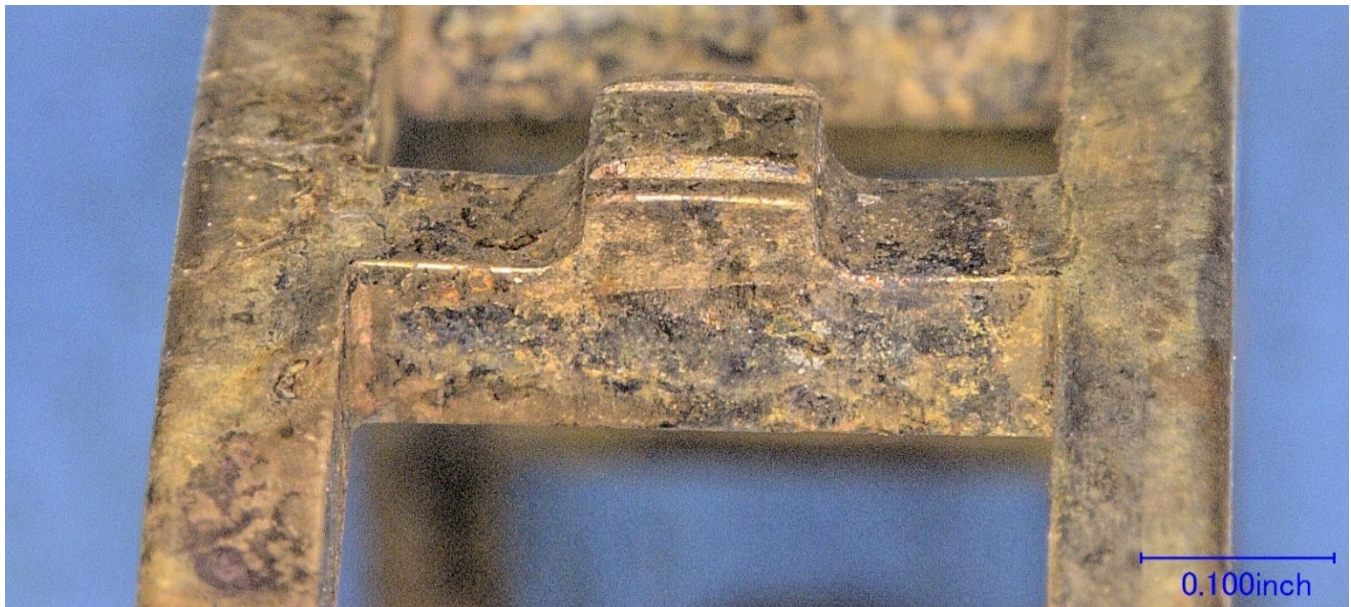


Figure 10 – A view of the pocket sides of the cage from the forward bearing, after full disassembly and cleaning. Mild wear marks could be observed on the side.



Figure 11 – The inner surface of the forward bearing cage, showing circumferential sliding wear, consistent with contact with the inner race.

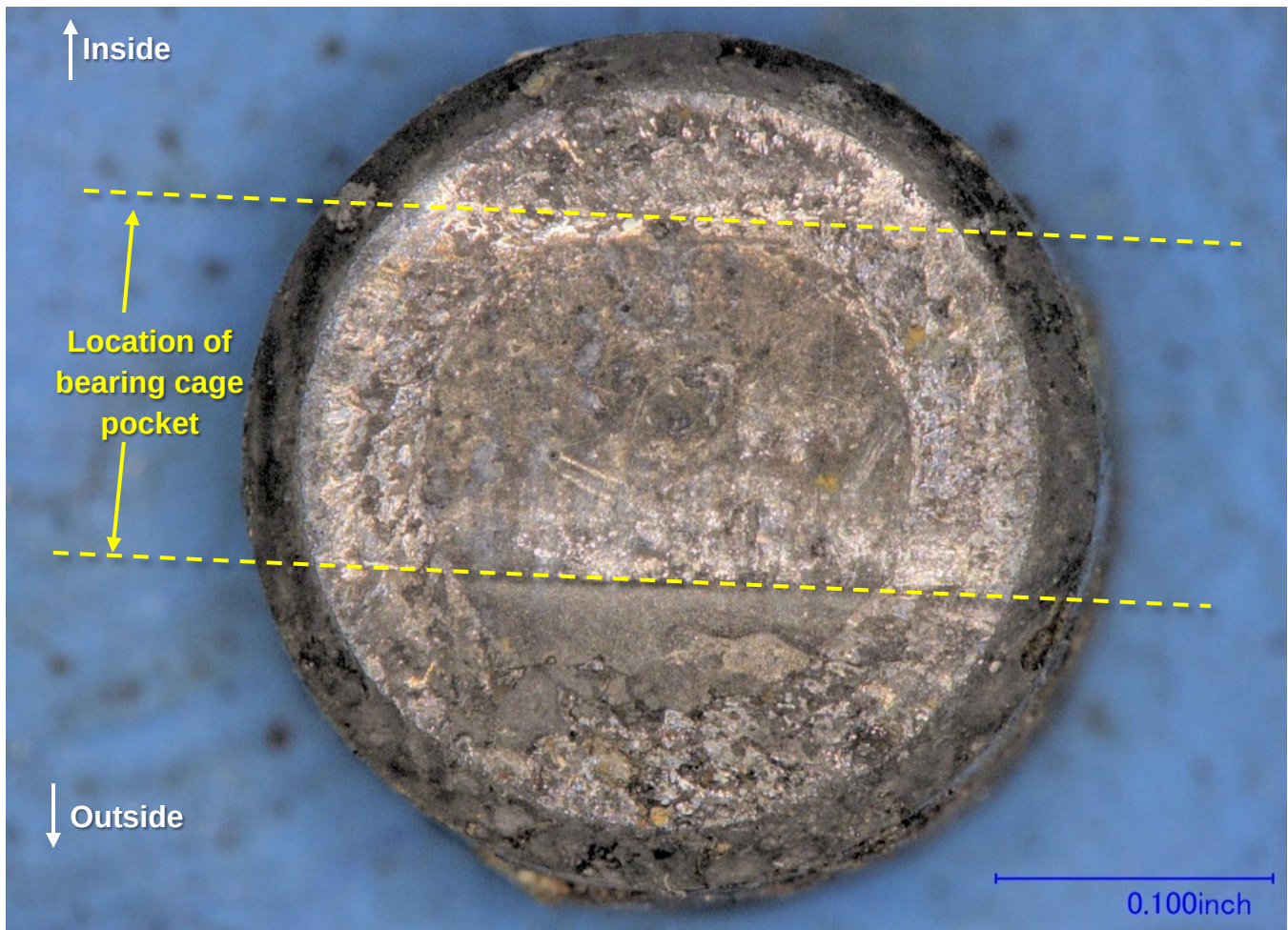


Figure 12 – A side view of one of the rollers from the forward bearing, after disassembly and cleaning. Horizontal wear marks were consistent with the location of the bearing cage and wear with the inner race channel.



Figure 13 – The outer face of the inner race of forward bearing, showing dents and depressions consistent with the rollers, and deformation of the aft surface flange.



Figure 14 – The inner race of the forward bearing, after cleaning, showing deformation of the aft flange and roller depressions.



Figure 15 – Closer view of the inner race channel from Figure 14, showing sliding wear marks with a roller.



Figure 16 – The inner surface of the forward bearing inner race, showing circumferential wear and gouging.

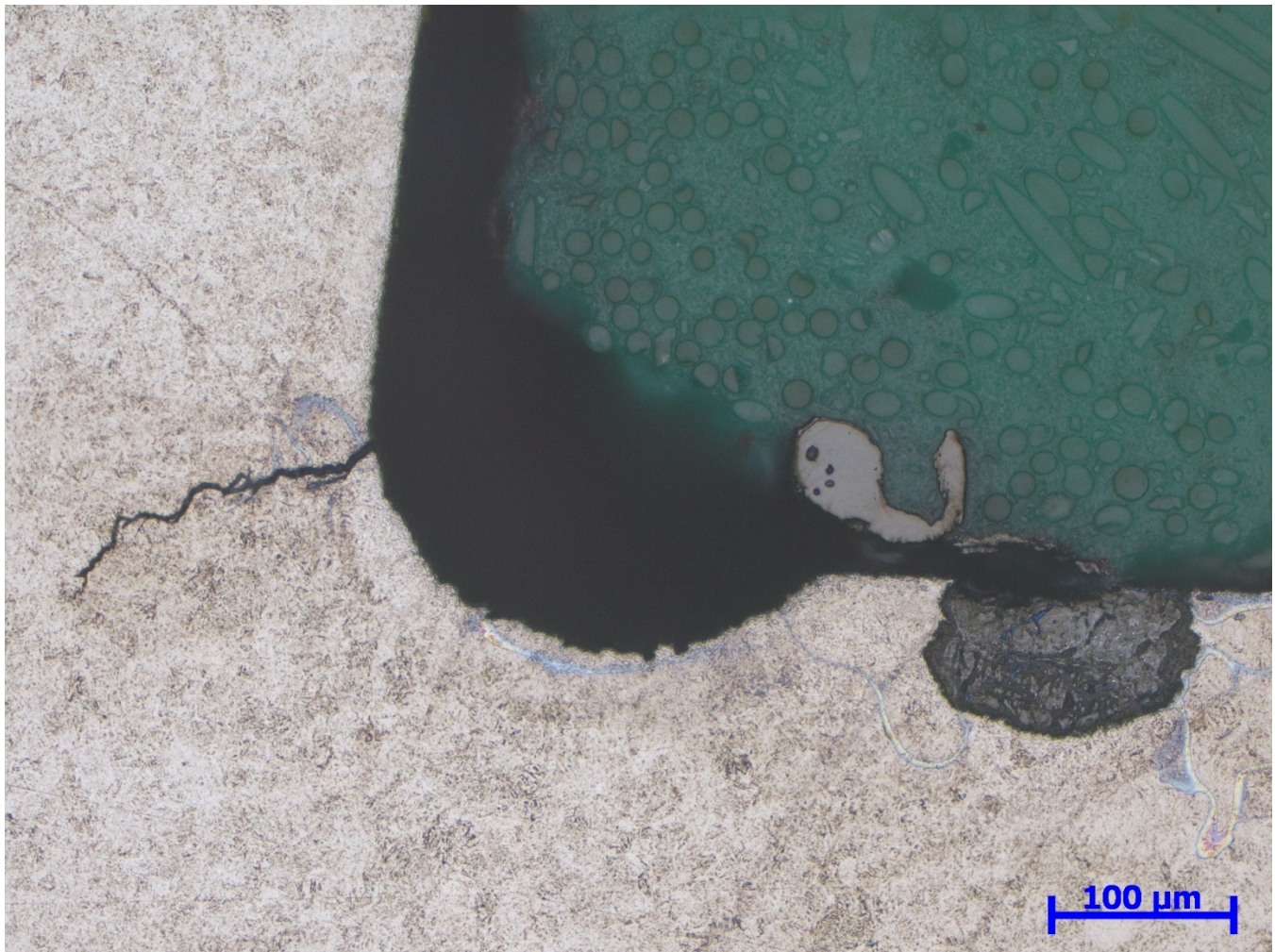


Figure 17 – Bright-field (BF) optical metallograph of the forward bearing inner race outer surface channel, showing corrosion pitting and a corner crack (~200X, etched 2% Nital).



Figure 18 – BF optical metallograph of the forward bearing inner race inner surface, showing microstructure contrast and subsurface oxidation (~100X, etched 2% Nital).

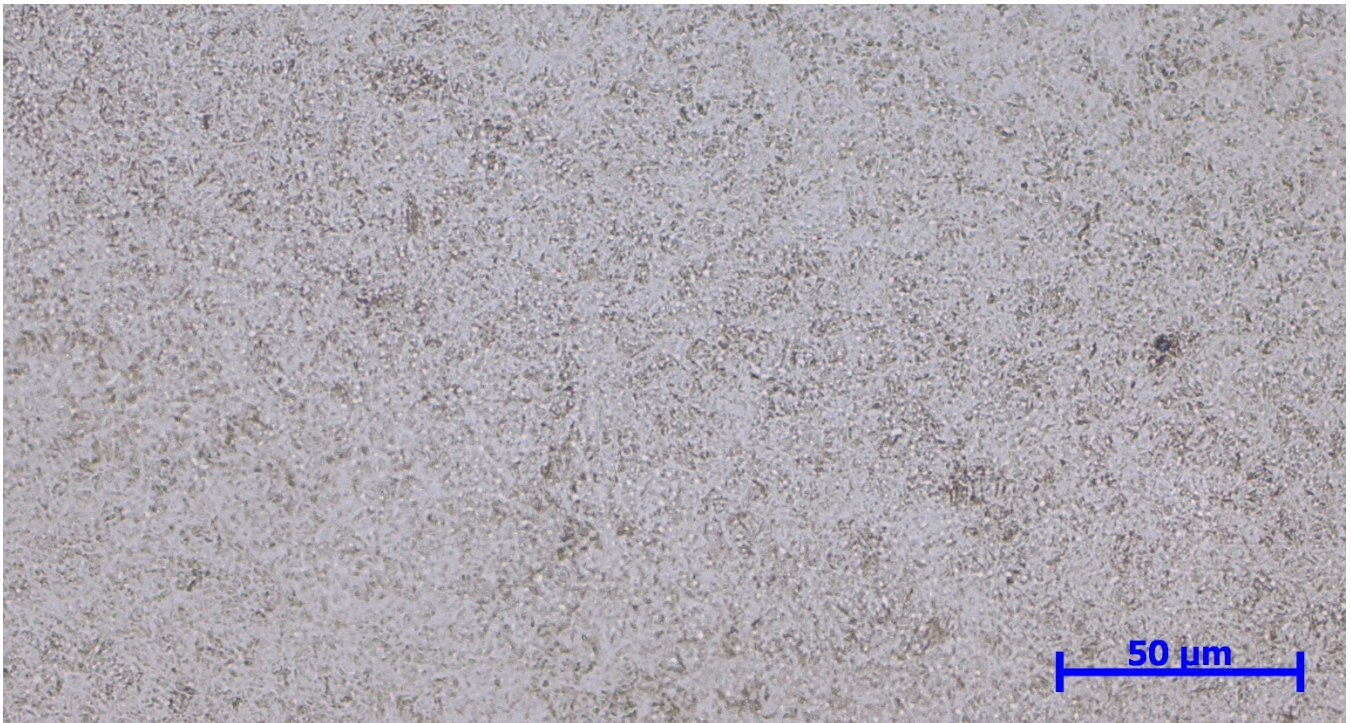


Figure 19 – BF optical metallograph of the forward bearing inner race, showing a typical area of microstructure away from the inner surface (~500X, etched 2% Nital).

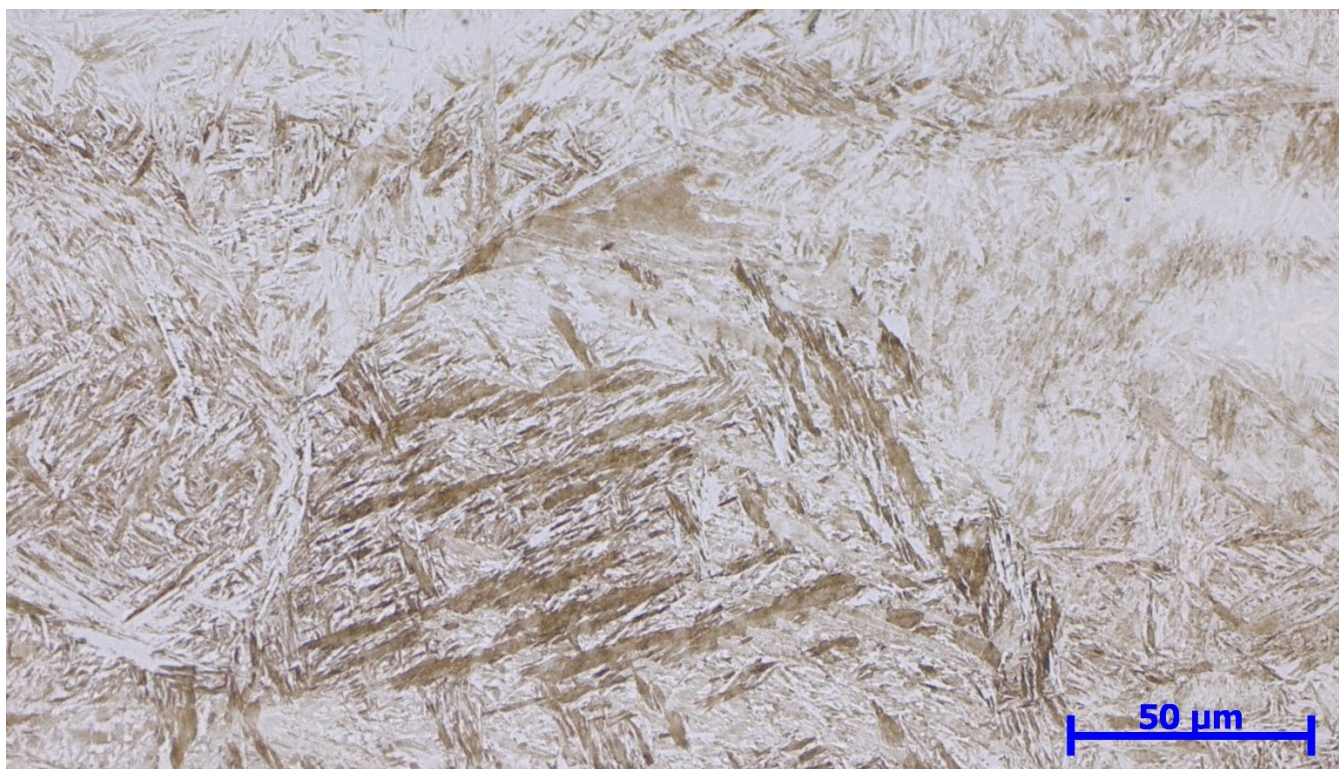


Figure 20 – BF optical metallograph of the forward bearing inner race, showing a typical area of microstructure near from the inner surface exhibiting martensite laths and prior austenite grain boundaries (~500X, etched 2% Nital).

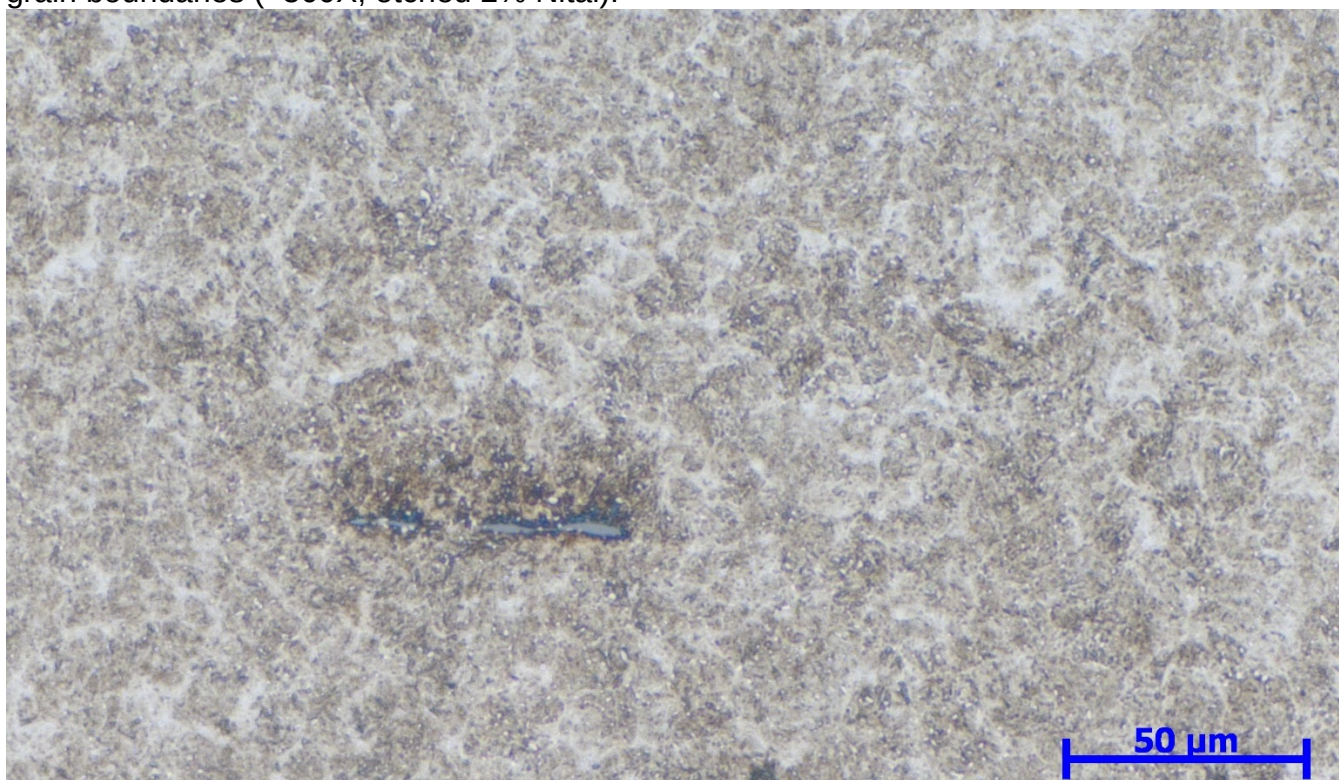


Figure 21 – BF optical metallograph of the forward bearing outer race, showing a typical area of microstructure (~500X, etched 2% Nital).

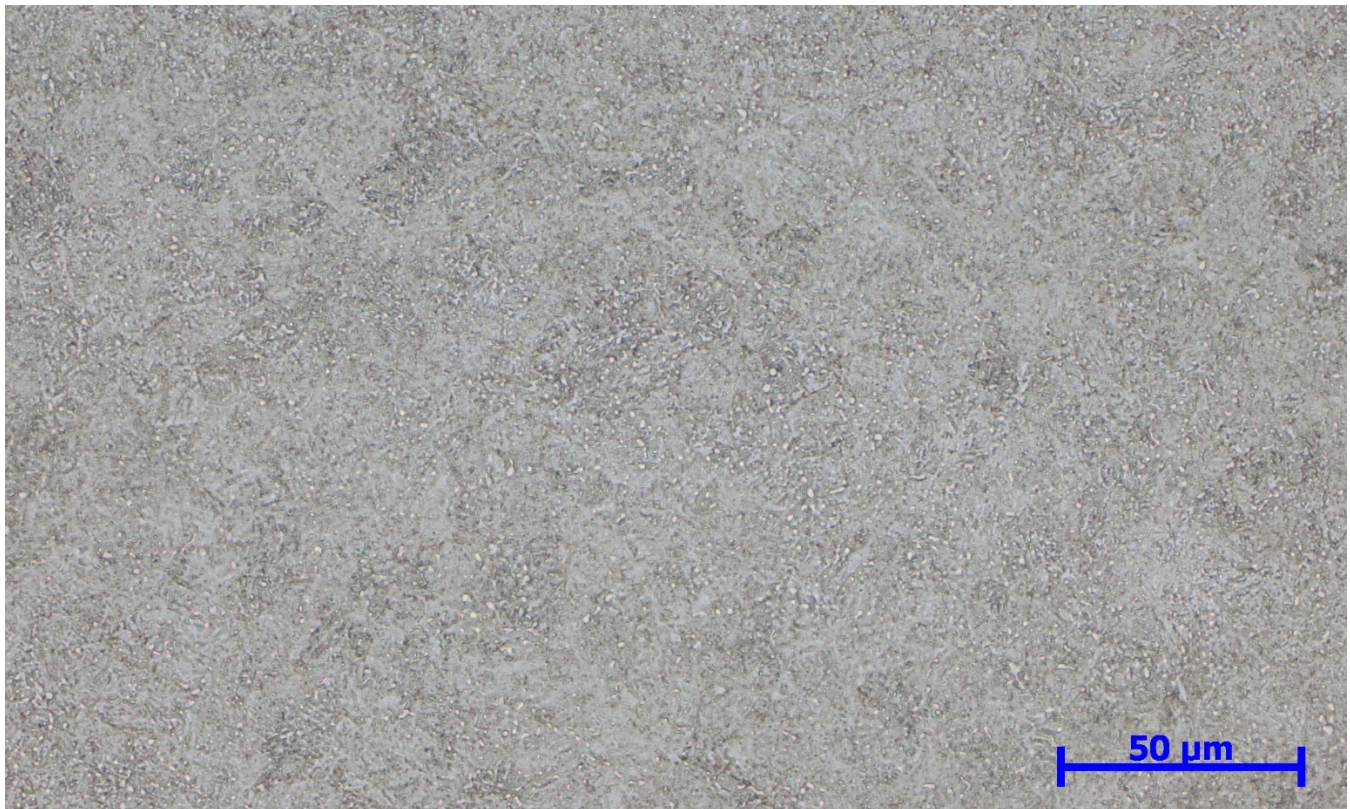


Figure 22 – BF optical metallograph of a forward bearing roller, showing a typical area of the microstructure (~500X, etched 2% Nital).

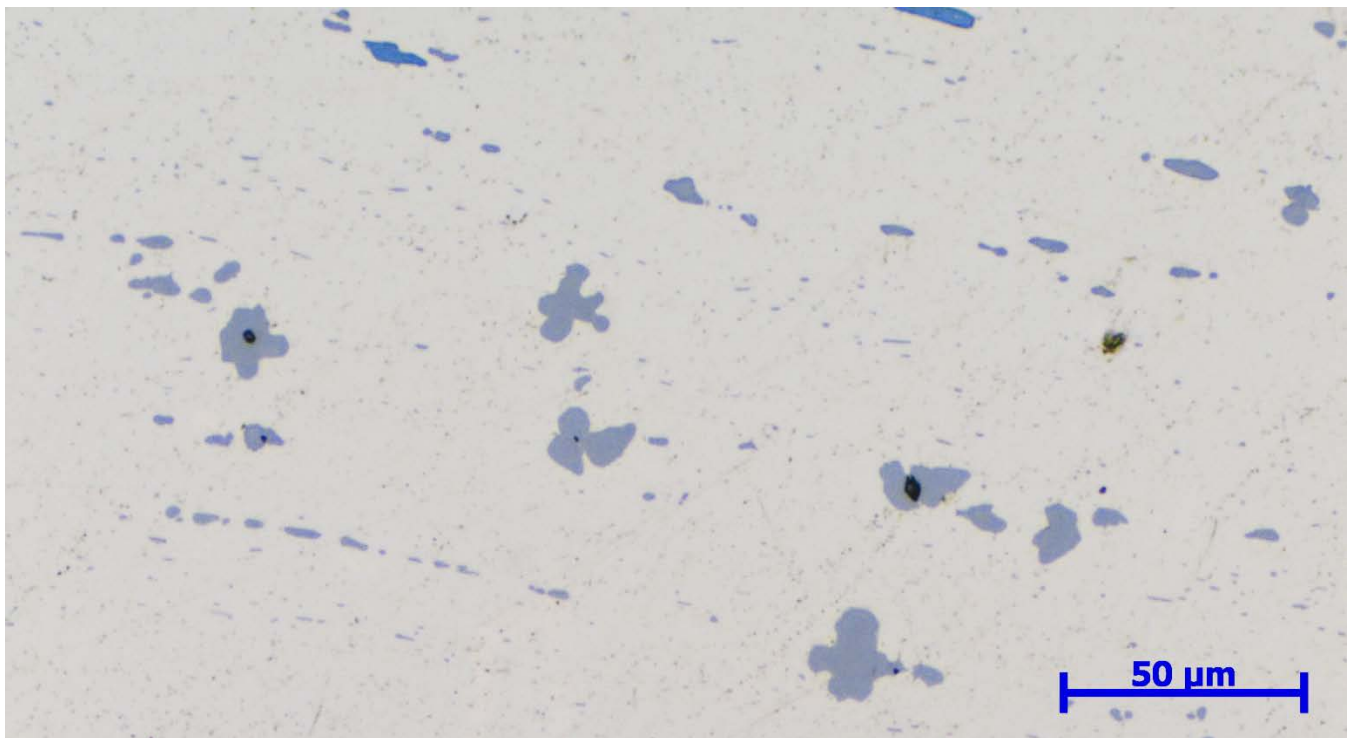


Figure 23 – BF optical metallograph of the forward bearing cage, showing a typical area of microstructure with the two phase microstructure of an α -brass (~500X, etched 2% Nital).



Figure 24 – The R44 shaft, showing the fracture location along the shaft taper, where the bearing assembly was positioned.

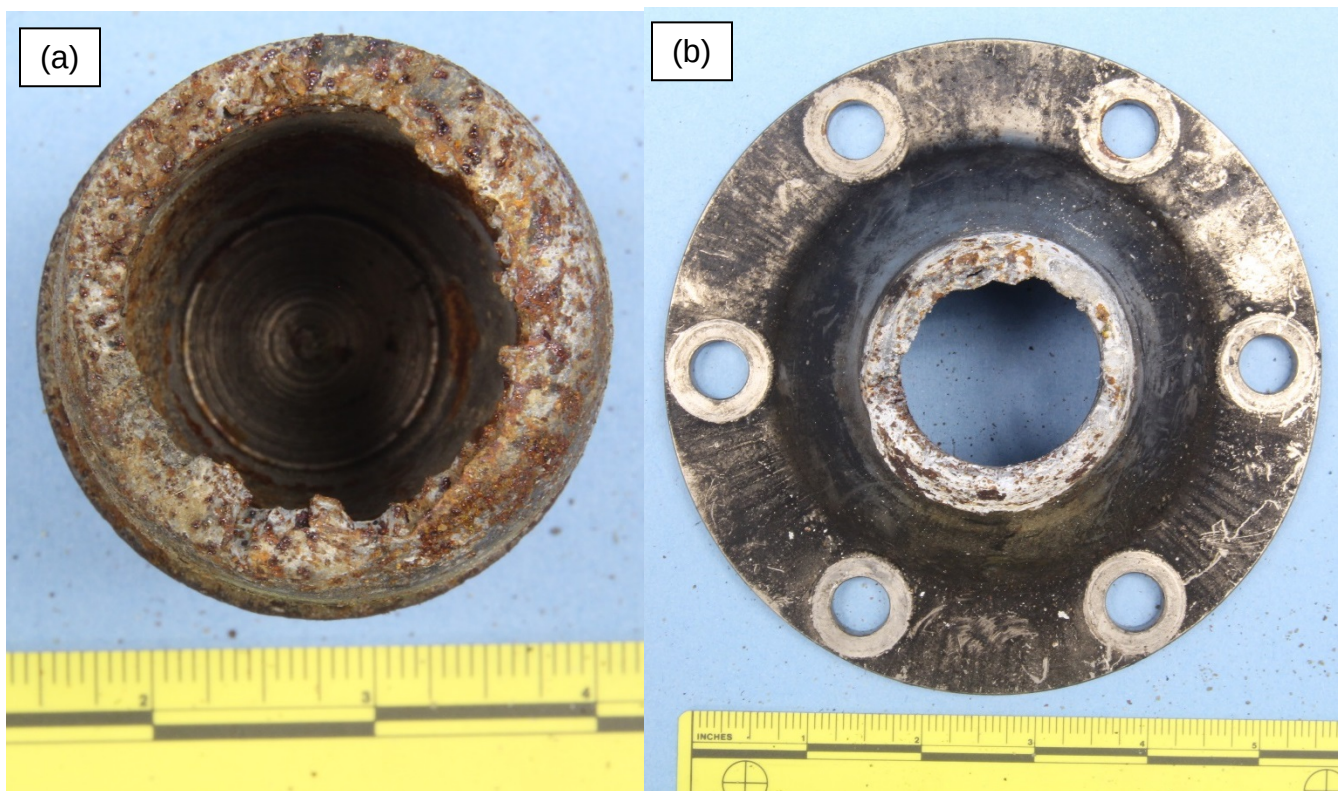


Figure 25 – The fracture surfaces of the bearing shaft, from (a) the aft side and (b) the forward side.



Figure 26 – Closer view of the aft side of the shaft, showing circumferential wear marks and deformation at the fracture.



Figure 27 – BF optical metallograph cross section of the fracture surface of the aft shaft section (reversed from Figure 26). The fracture was located on the left (~500X, etched 2% Nital).

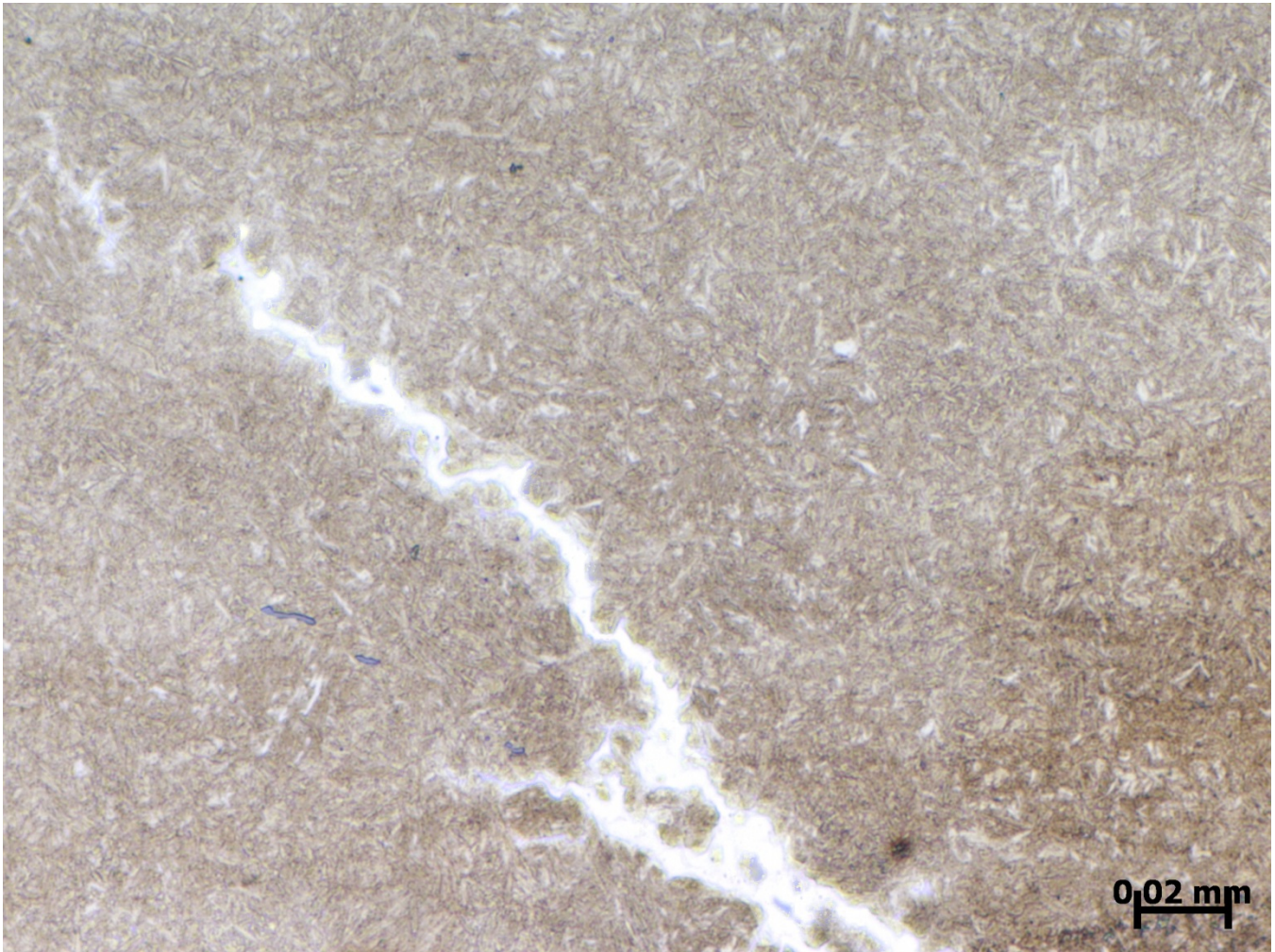


Figure 28 – BF optical metallograph showing a subsurface white layer near the fracture surface tip (~500X, etched 2% Nital).